Why Wind Works: Denmark's Model for Sustainability

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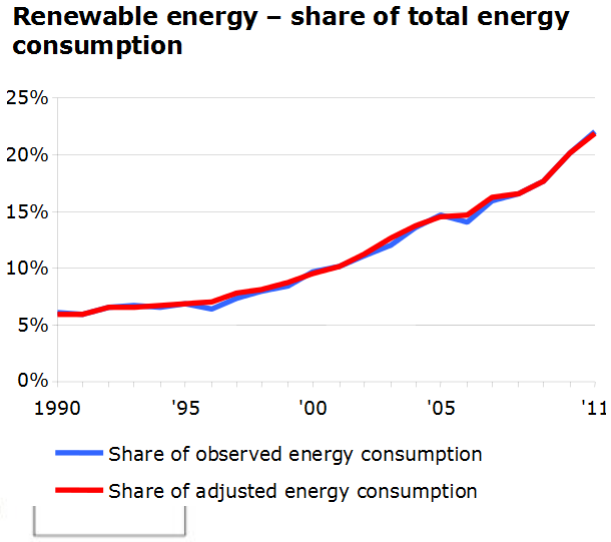
DTU Management Engineering
Department of Management Engineering

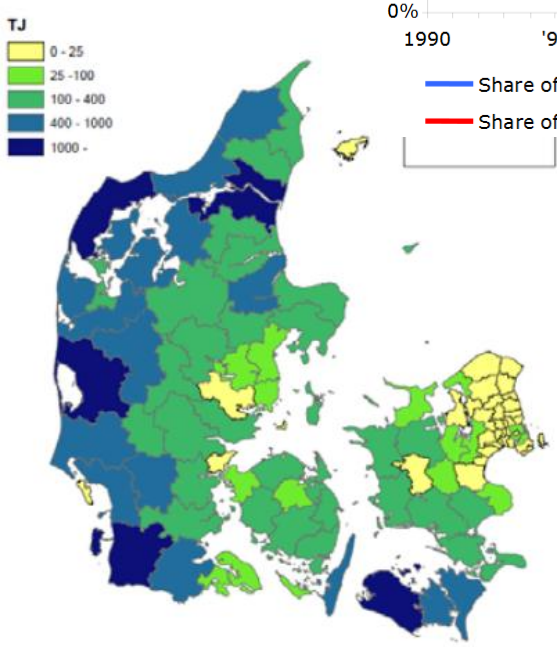
Why Wind Works: Denmark's Model for Sustainability

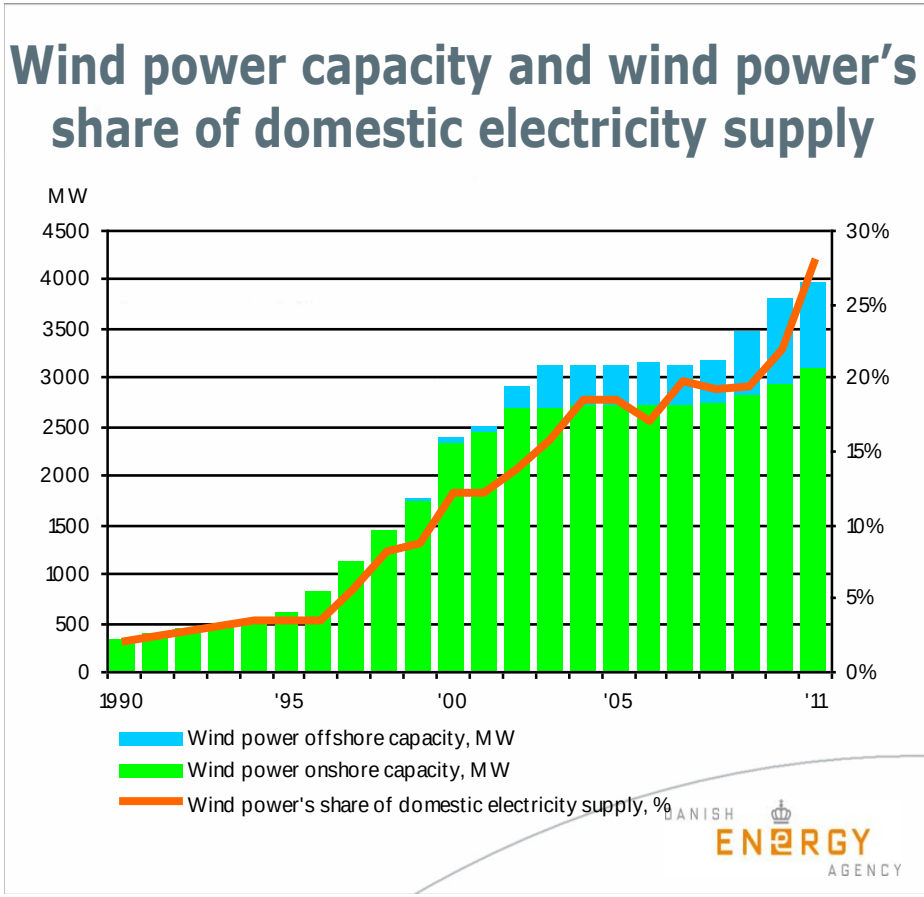
AGENDA

- Favourable position – power highway continent - Scandinavia
- Excess generation capacity
- Flexible hydro storage in Norway
- Moving wind expansion off-shore
- Relatively shallow off-shore locations with medium costs
- Nice off-shore planning environment
- Price effects but they can be accommodated
- High consumer prices for power and willingness to pay among residential customers

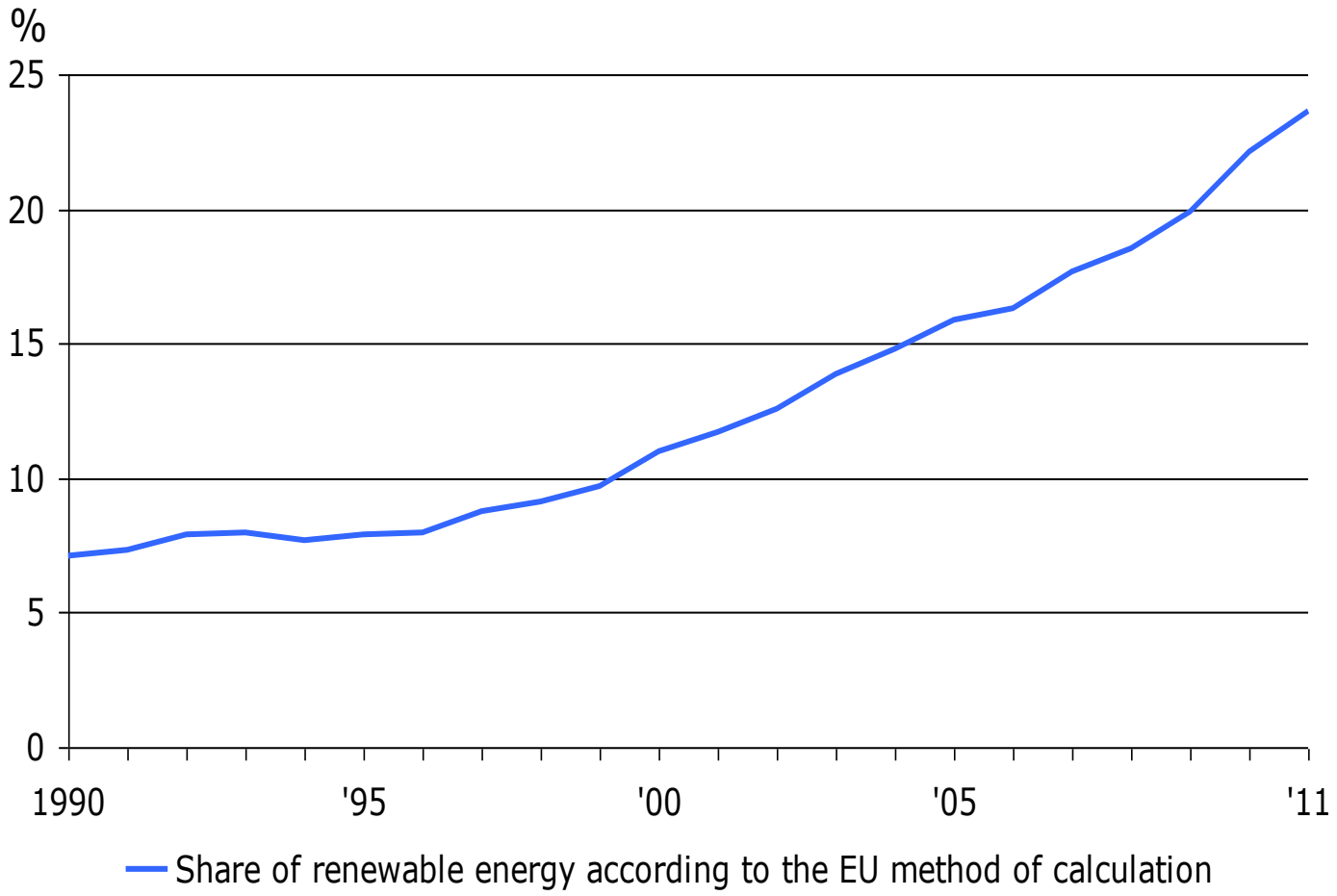
What has been achieved: Renewable energy







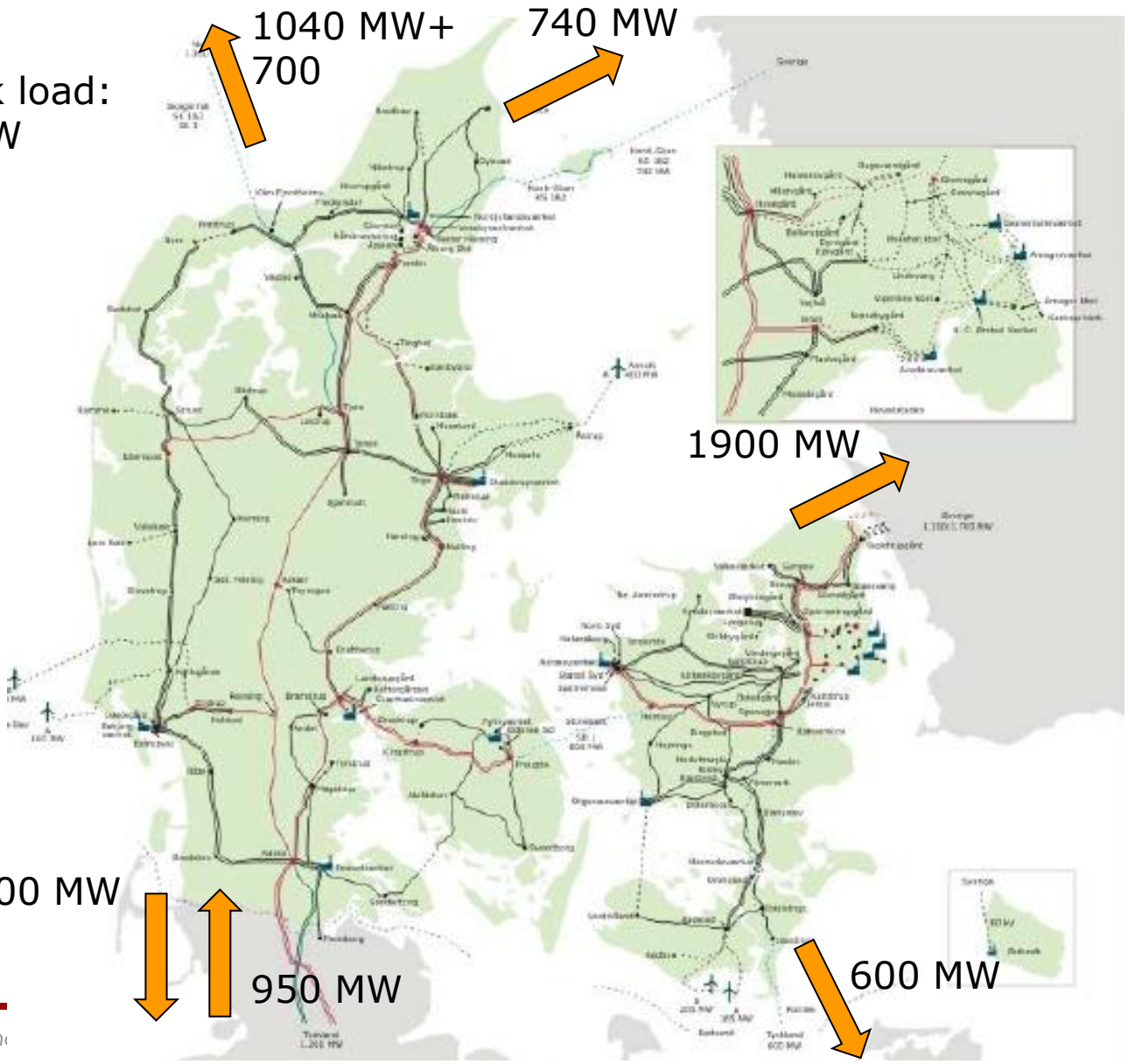
Share of renewable energy and EU target for Denmark (EU method)

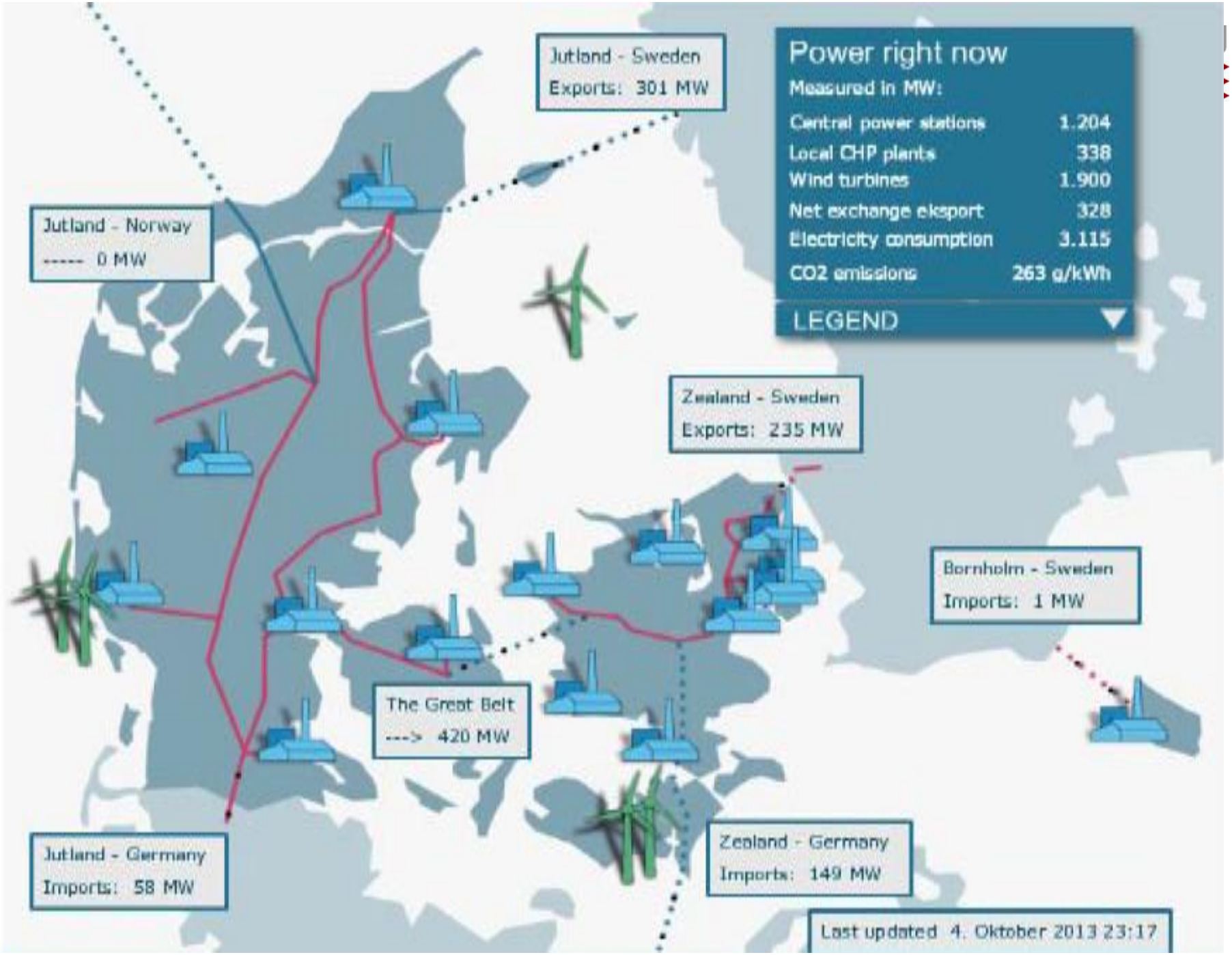


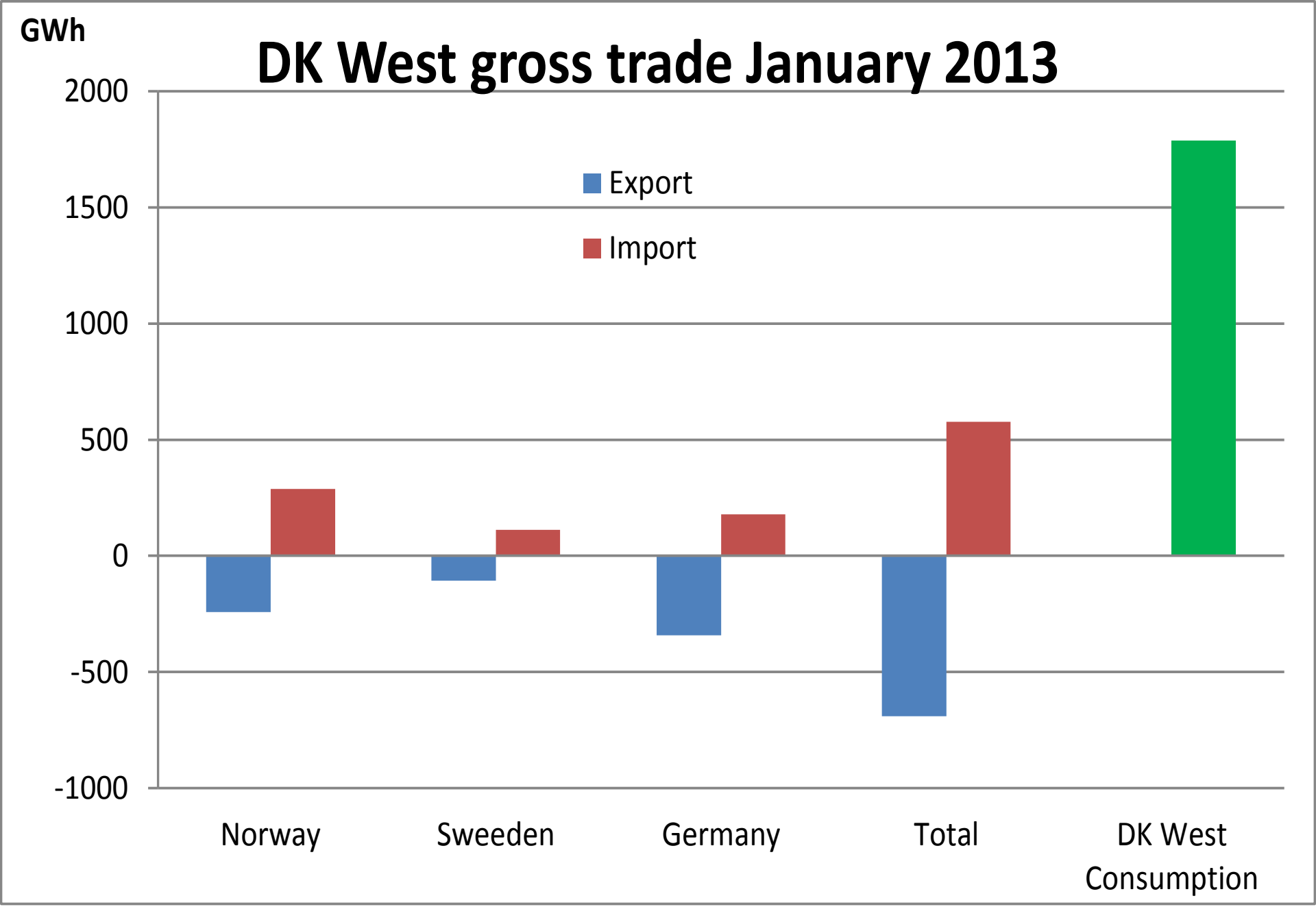
EU target for Denmark in 2020: **30%**

Strong interconnections

DK peak load:
6500 MW




Jutland - Sweden
Exports: 301 MW
Power right now
Measured in MW:
Central power stations 1.204
Local CHP plants 338
Wind turbines 1.900
Net exchange eksport 328
Electricity consumption 3.115
CO2 emissions 263 g/kWh
LEGEND
Jutland - Norway
----- 0 MW
Zealand - Sweden
Exports: 235 MW
Bornholm - Sweden
Imports: 1 MW
The Great Belt
---> 420 MW
Jutland - Germany
Imports: 58 MW
Zealand - Germany
Imports: 149 MW
Last updated 4. Oktober 2013 23:17


GWh
DK West gross trade January 2013
2000
1500
1000
500
0
-500
-1000
Export
Import
Norway
Sweeden
Germany
Total
DK West Consumption

Excess power capacity – still?

Nordic system power balance

POWER BALANCE 2012-2013

With estimated power exchange [MW]

Cold winter day in 1 of 10 winters

NORDIC MARKET		TOTAL
P =	Available capacity TSO reserves excluded	72 930
C =	Peak demand	*) 71 640
B =	Balance without power exchange	1 290
R =	Reserves available for the TSOs	4 750

*) 2 % lower than sum of national peaks.

Arrows between and to/from the Nordic countries indicate the most probable power flow direction during peak hou

Hydro

SWEDEN	
P	27 700
C	27 500
B	200
R	1 400

FINLAND	
P	13 300
C	15 000
B	-1 700
R	1 100

NORWAY	
P	26 200
C	24 000
B	2 200
R	1 200

Wind capacity value of 4000 MW

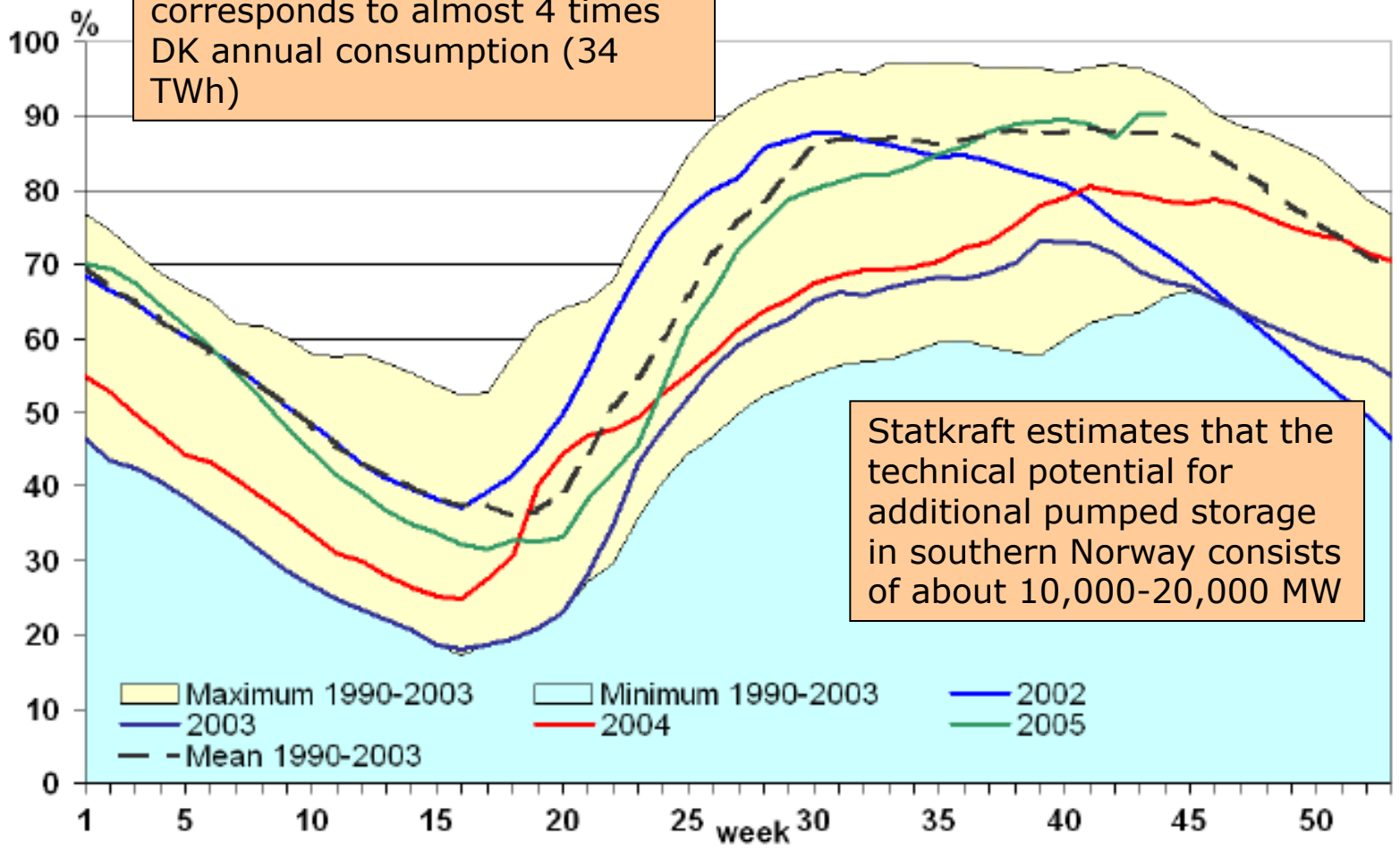
Excluded

DENMARK	
P	5 730
C	6 600
B	-870
R	1 050

Norwegian hydropower – flexible storage

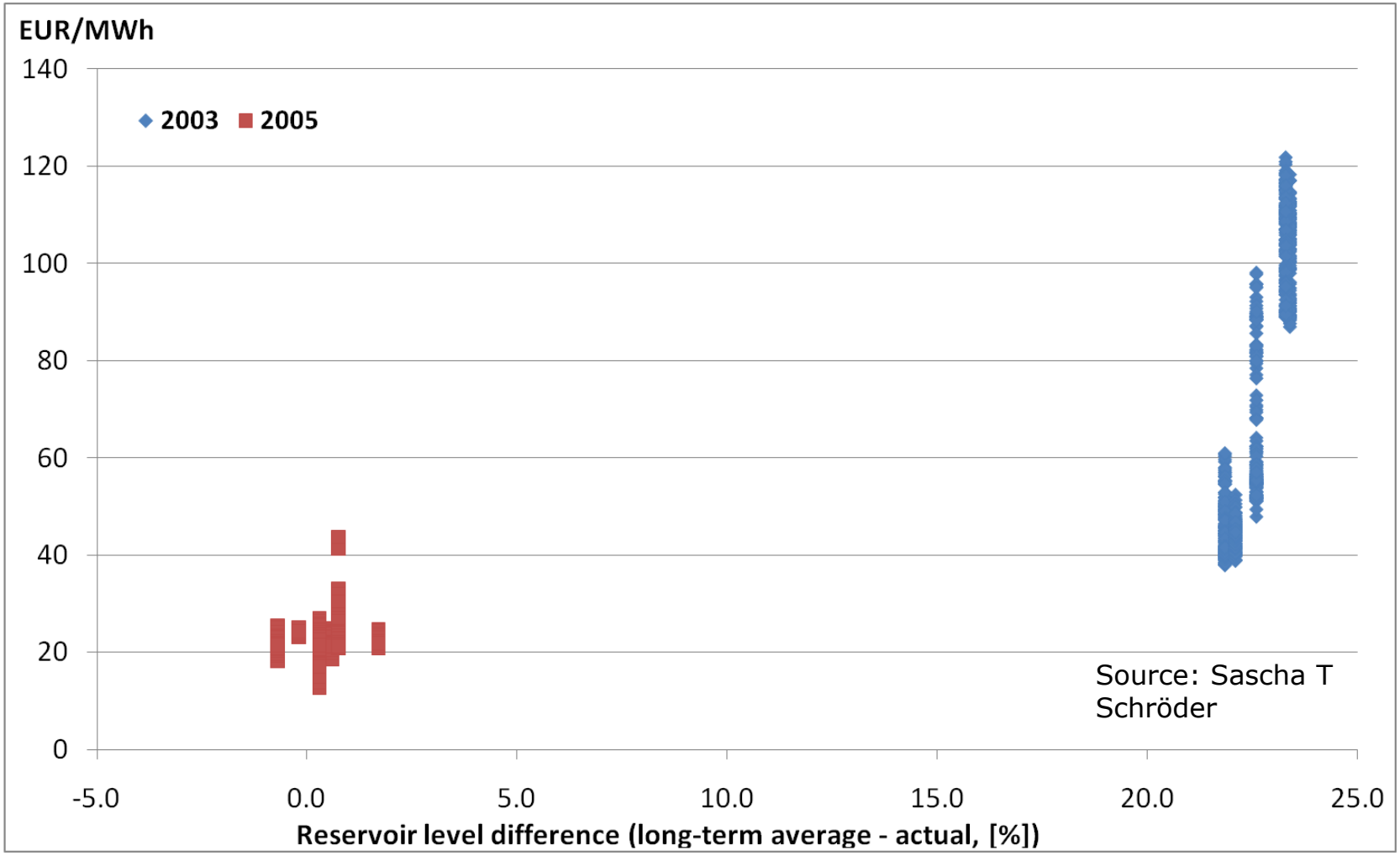
Norwegian reservoir levels vary but capacity and prospects for pumped hydro large

Total hydropower capacity in Norway: approx 124 TWh corresponds to almost 4 times DK annual consumption (34 TWh)



Statkraft estimates that the technical potential for additional pumped storage in southern Norway consists of about 10,000-20,000 MW

Norway: Reservoir levels and prices



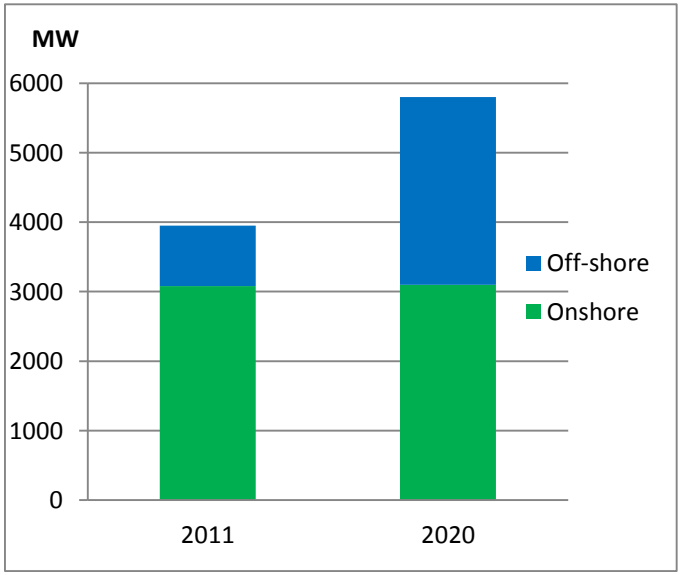
Moving off-shore

The Anholt wind power plant's total installed electrical generating capacity of 400 megawatts is enough to supply around 400,000 Danish households with clean power, thereby meeting about four percent of Denmark's total power demand.
Anholt consists of 111 wind turbines with a capacity of 3.6 megawatt each and a rotor diameter of 120 meters

2013-Sep-04
Official opening of the Anholt Offshore Wind Farm on Wednesday, September 04, 2013 (from left) Danish Prime Minister Helle Thorning-Schmidt, Her Majesty Queen Margrethe II of Denmark, His Royal Highness Prince Henrik, Prince Consort of Denmark, and Fritz Schur, Chairman of the Board of Directors for DONG Energy.

Danish offshore wind turbine development and projects in planning

Location	Size
1. Vindeby (1991)	11 turbines, 5 MW
2. Tunø Knob (1995)	10 turbines, 5 MW
3. Middelgrunden (2000)	20 turbines, 40 MW
4. Horns Rev I (2002)	80 turbines, 160 MW
5. Rønland (2003)	8 turbines, 17 MW
6. Nysted (2003)	72 turbines, 165 MW
7. Samsø (2003)	10 turbines, 23 MW
8. Frederikshavn (2003)	3 turbines, 7 MW
9. Horns Rev II (2009)	91 turbines, 209 MW
10. Avedøre Holme (2009/10)	3 turbines, 10-13 MW
11. Sprogø (2009)	7 turbines, 21 MW
12. Rødsand II (2010)	90 turbines, 207 MW
13. Anholt (2012/13)	400 MW
14. Horns Rev III (2017/18)	400 MW
15. Kriegers Flak (2017/19)	600 MW
Coastal areas off-shore (2016/20)	500 MW
Additional planned sites?	3200 MW

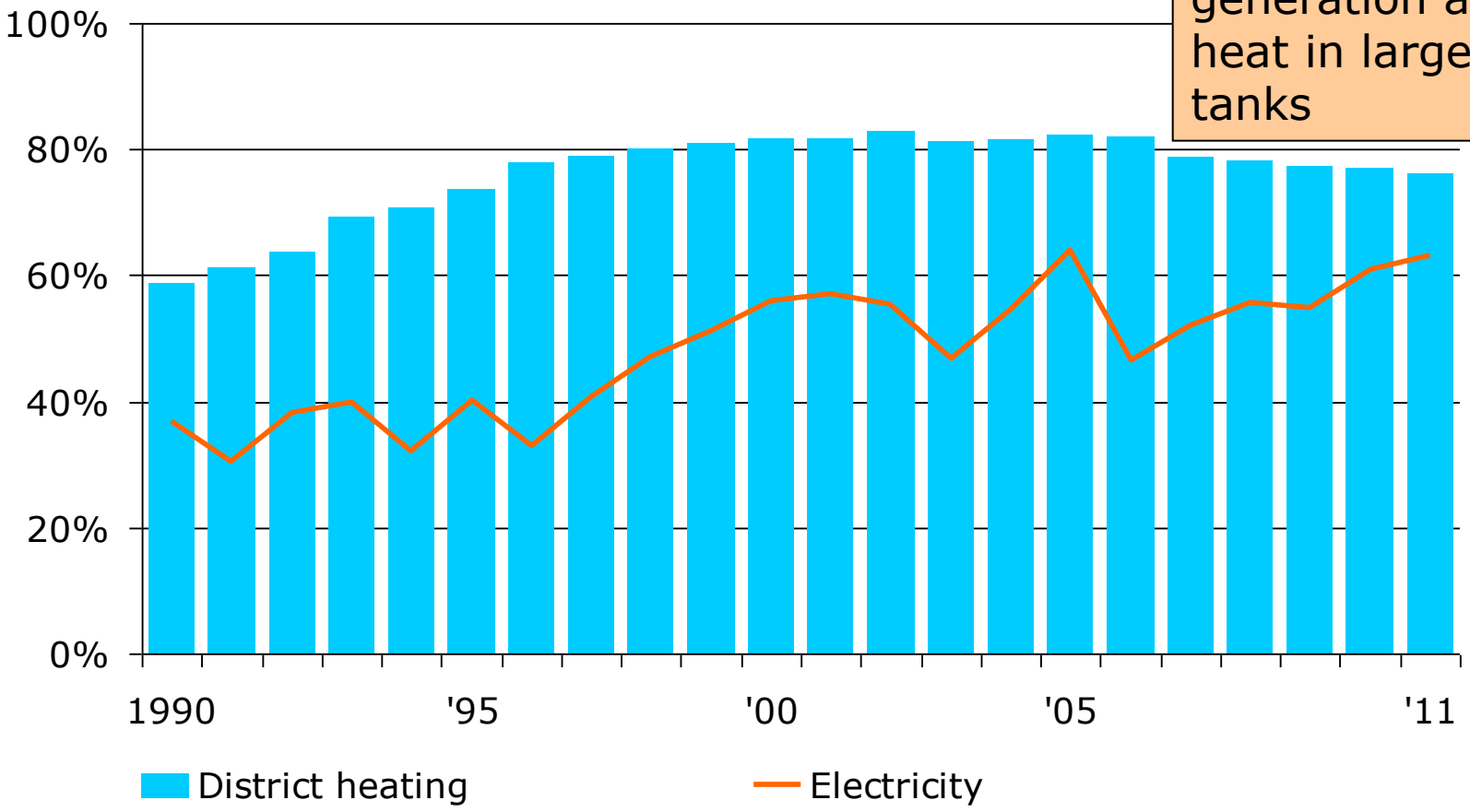


Size has changed dramatically also for the installation infrastructure
Offshore installation vessels for WT are a critical planning resource

Danish district heating and heat pumps supply flexibility

Combined Heat and Power (CHP) share of thermal power and district heating production

CHP provide flexibility in case of high wind generation and store heat in large storage tanks



Heat pumps adds flexibility

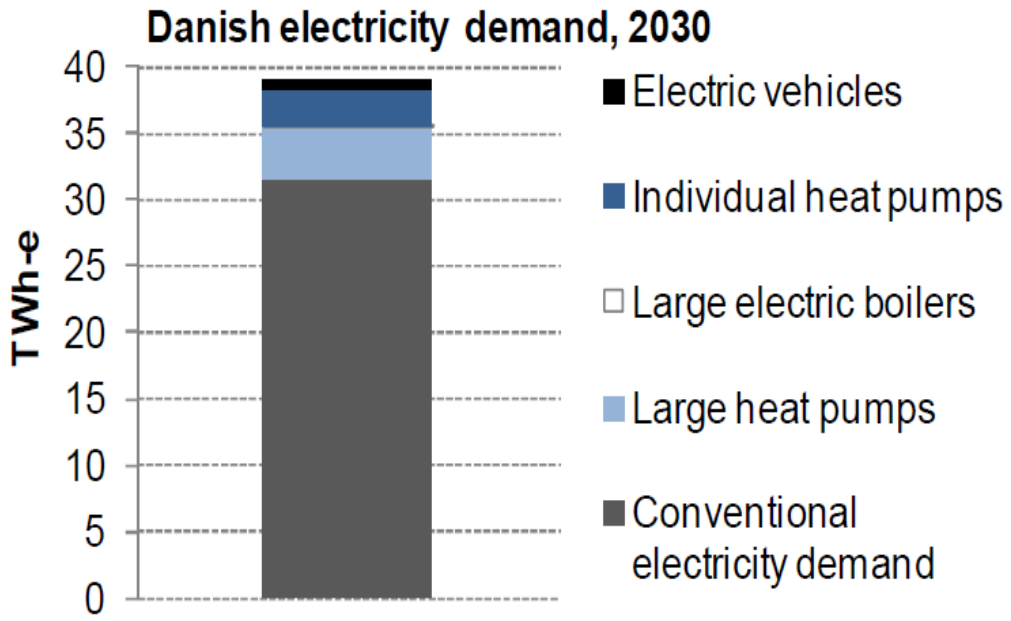
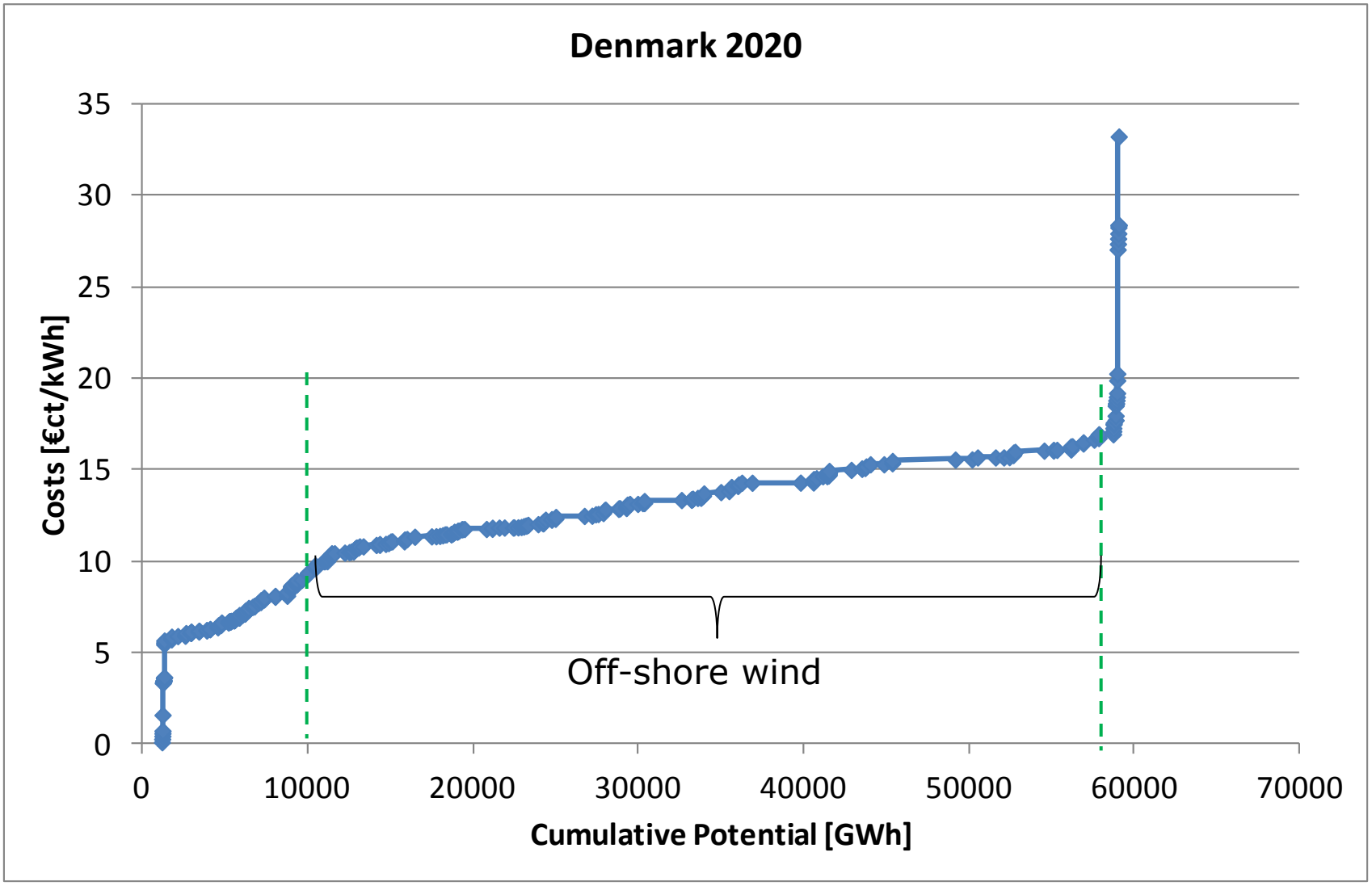


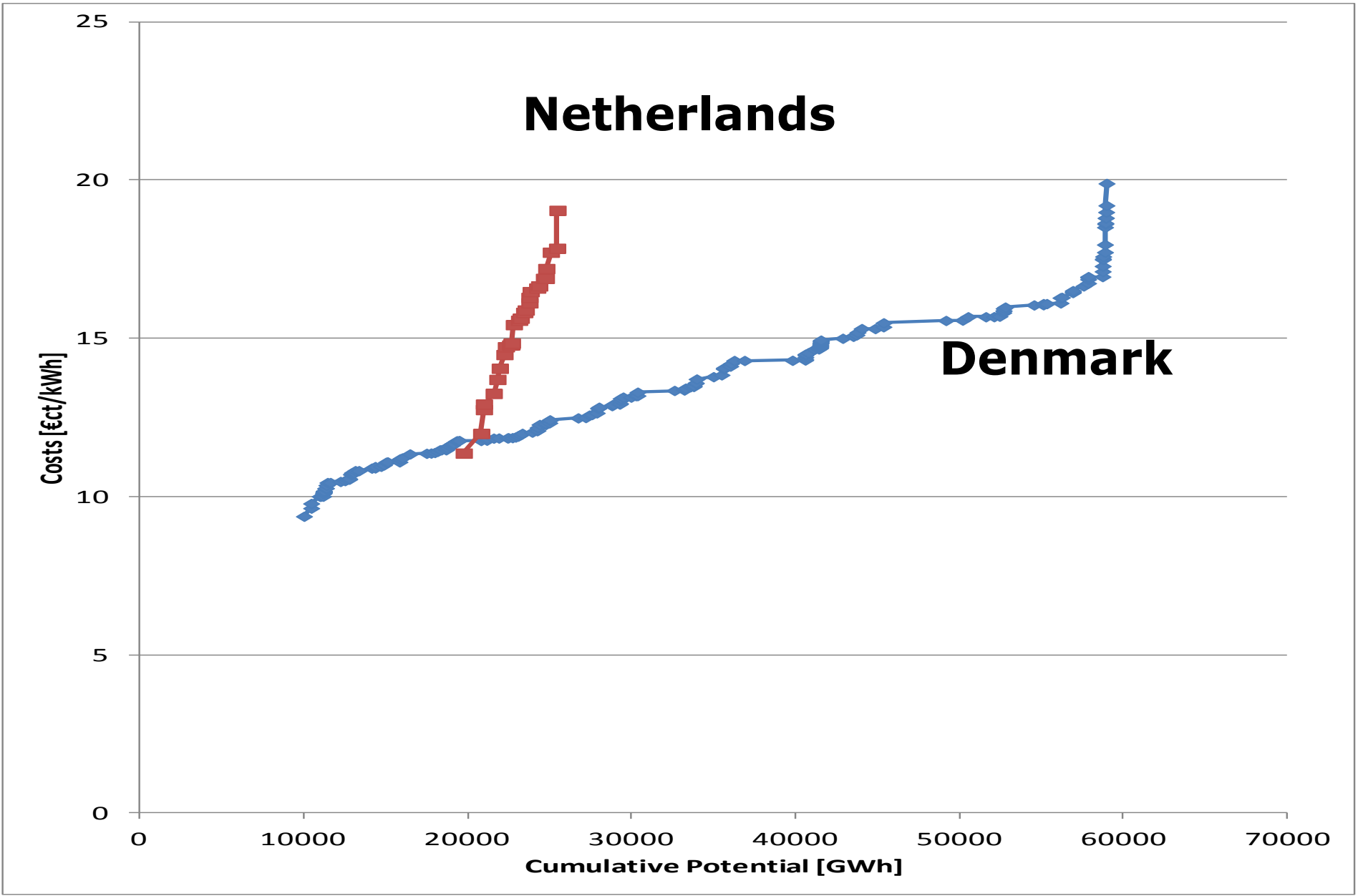
Figure 2. Danish electricity demand in 2030 as expected by Energinet.dk (incl. grid losses) [5].

Favourable costs and planning conditions for adding more off-shore wind

RES-E potential in Denmark from RES4LESS project



Offshore wind generation costs projected to 2020



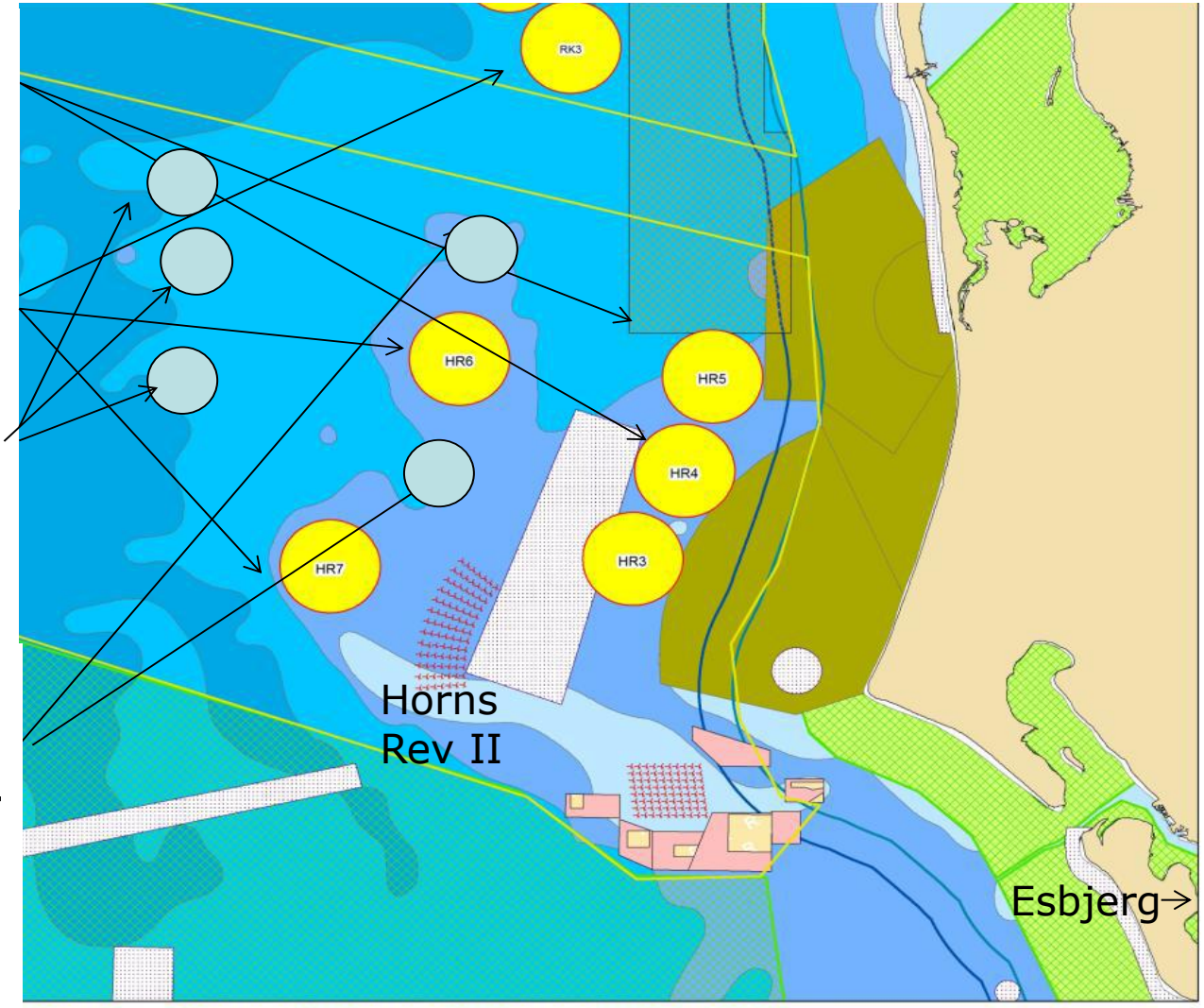
Horns Rev planned (yellow) wind farms and additional options

Shallow with low cost

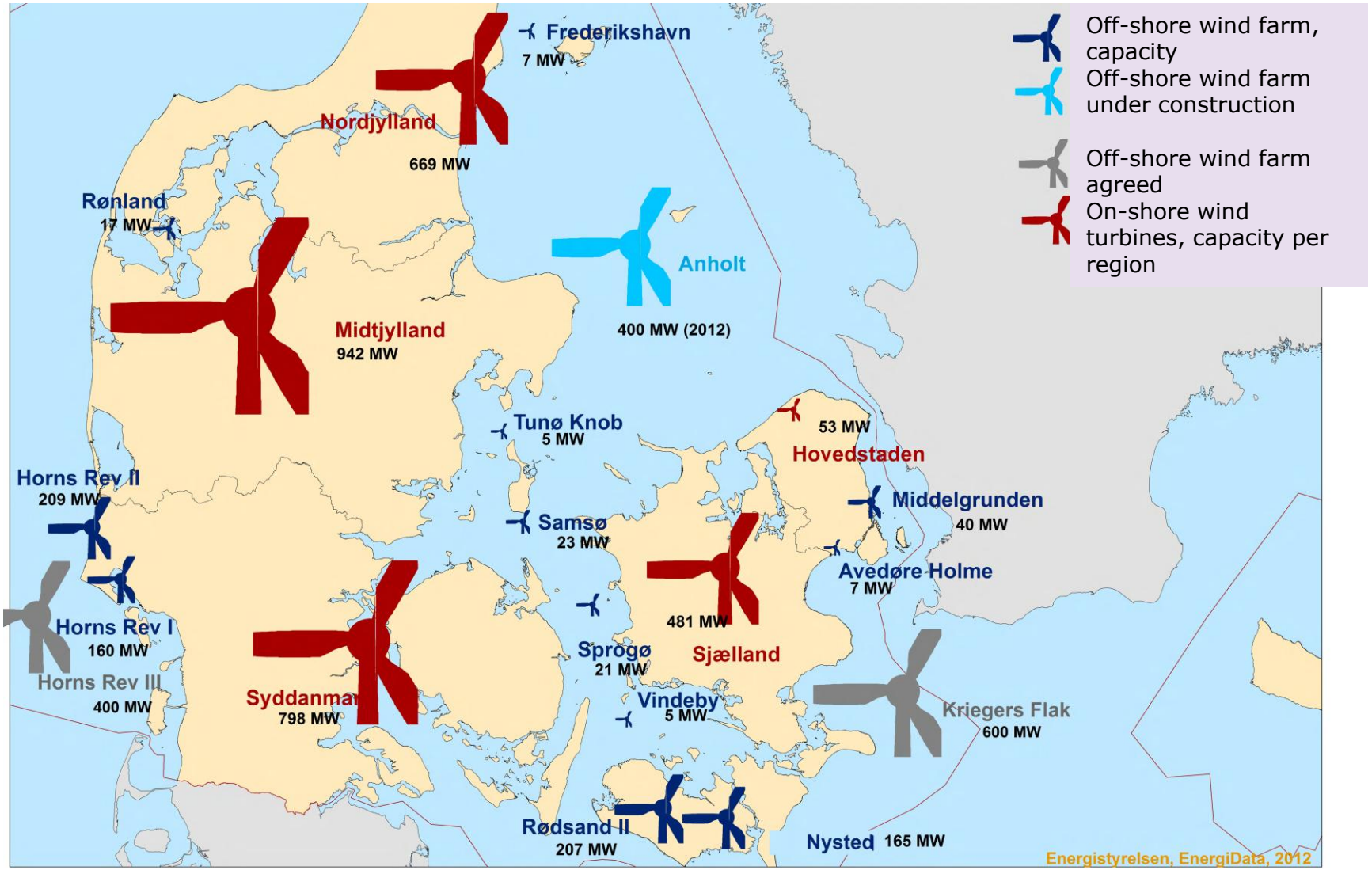
Medium cost location

Additional deeper locations with higher costs

Locations with minor negative costs on neighbour wind farms



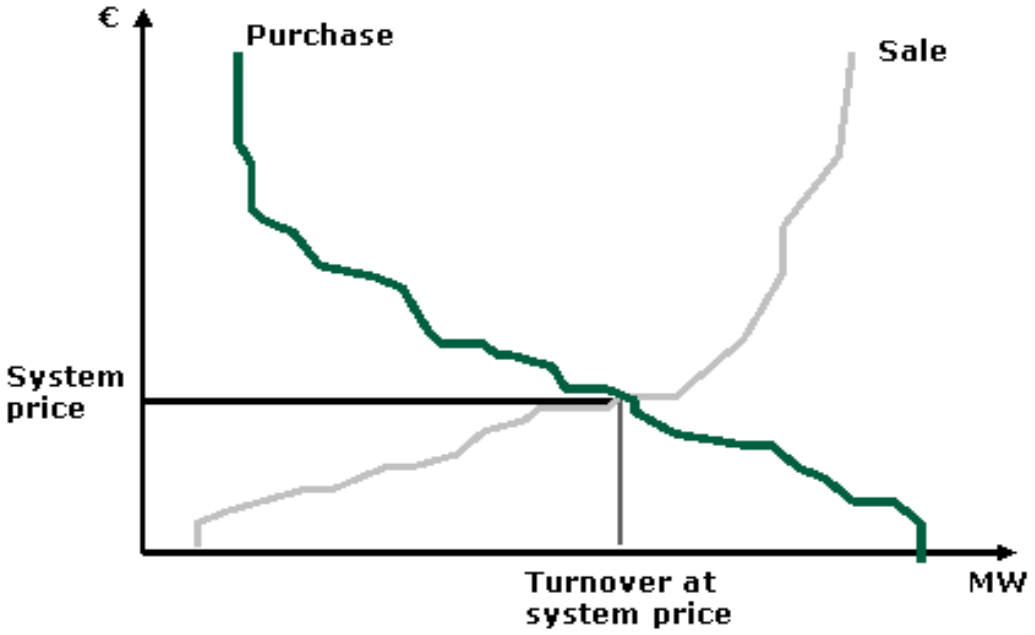
Off-shore and on-shore wind capacity



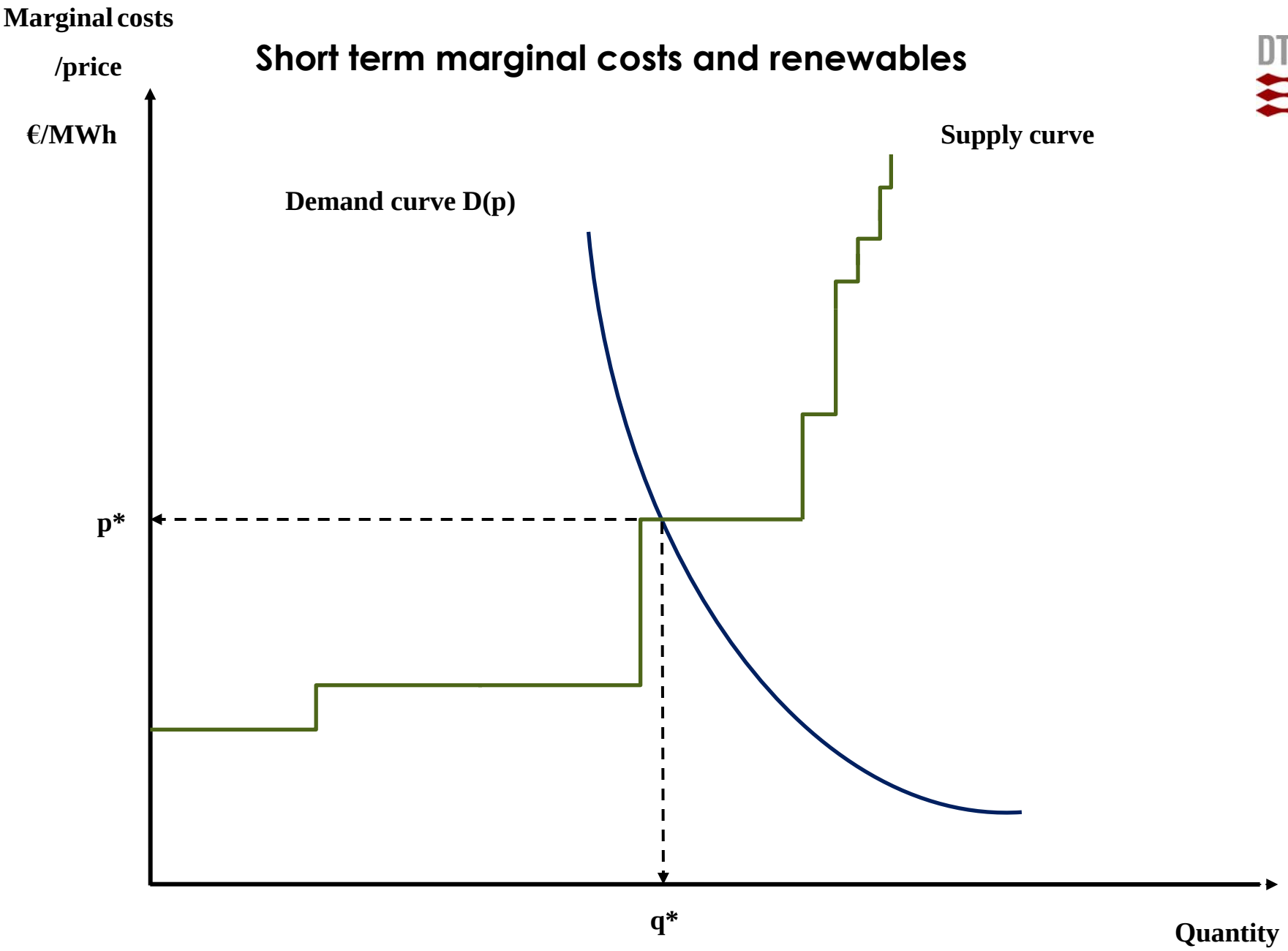
Additional wind generation reduce wholesale prices but it can be accommodated

Electricity markets: standard supply and demand

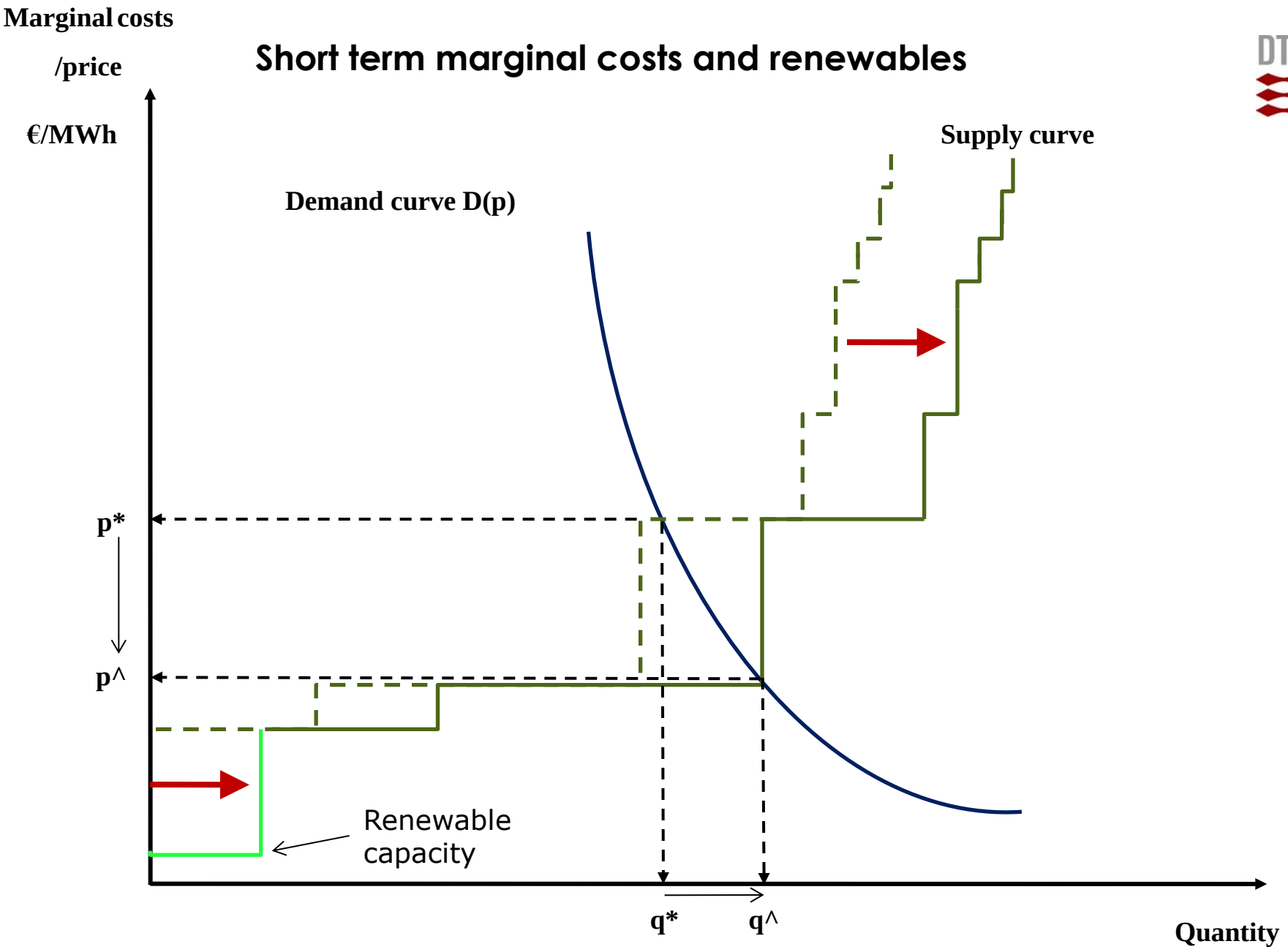
- Spot (day ahead) markets
- European spot markets (day ahead), hourly resolution
- Buyers and sellers bid *stepped curves*



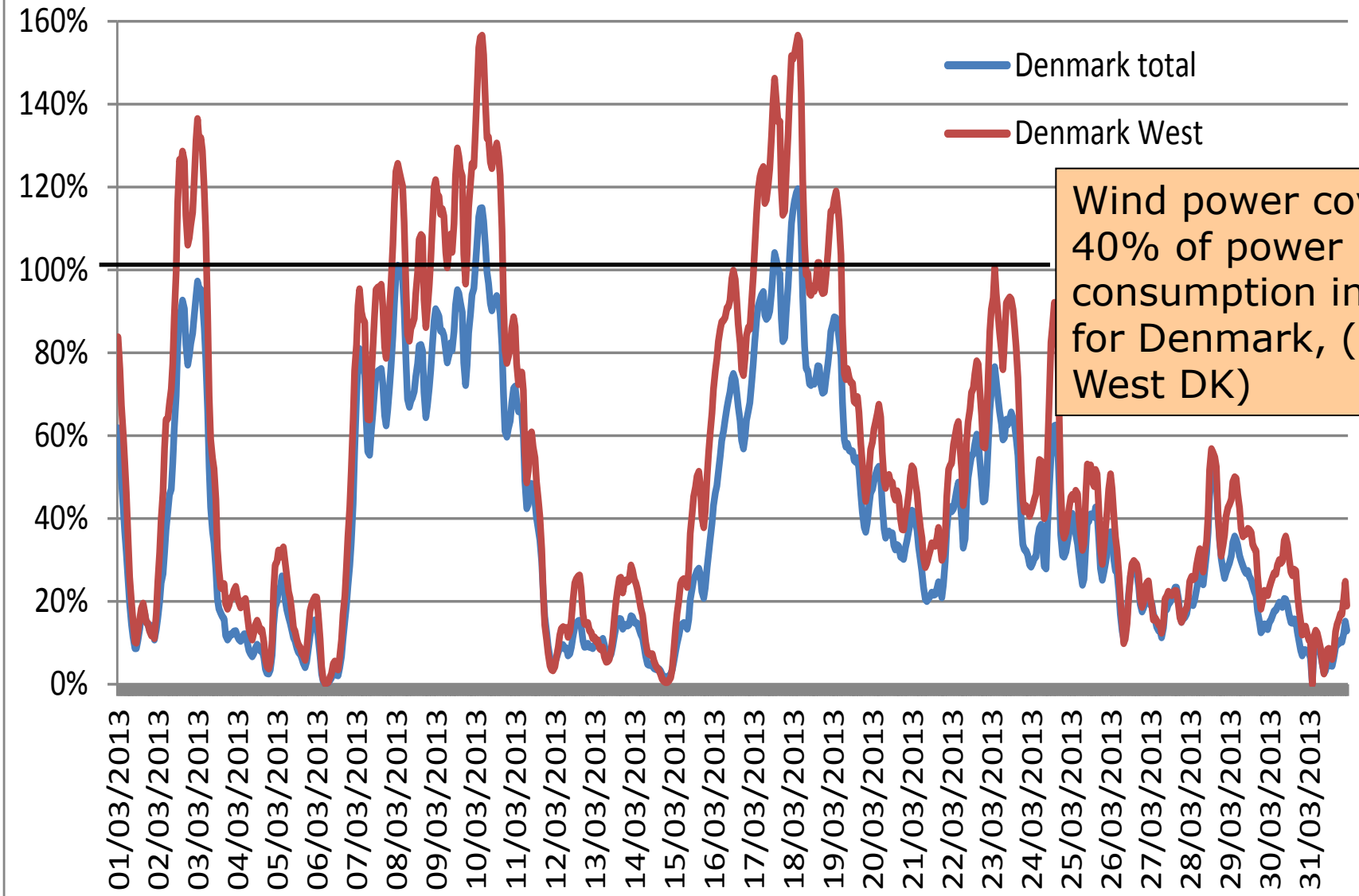
Short term marginal costs and renewables



Short term marginal costs and renewables

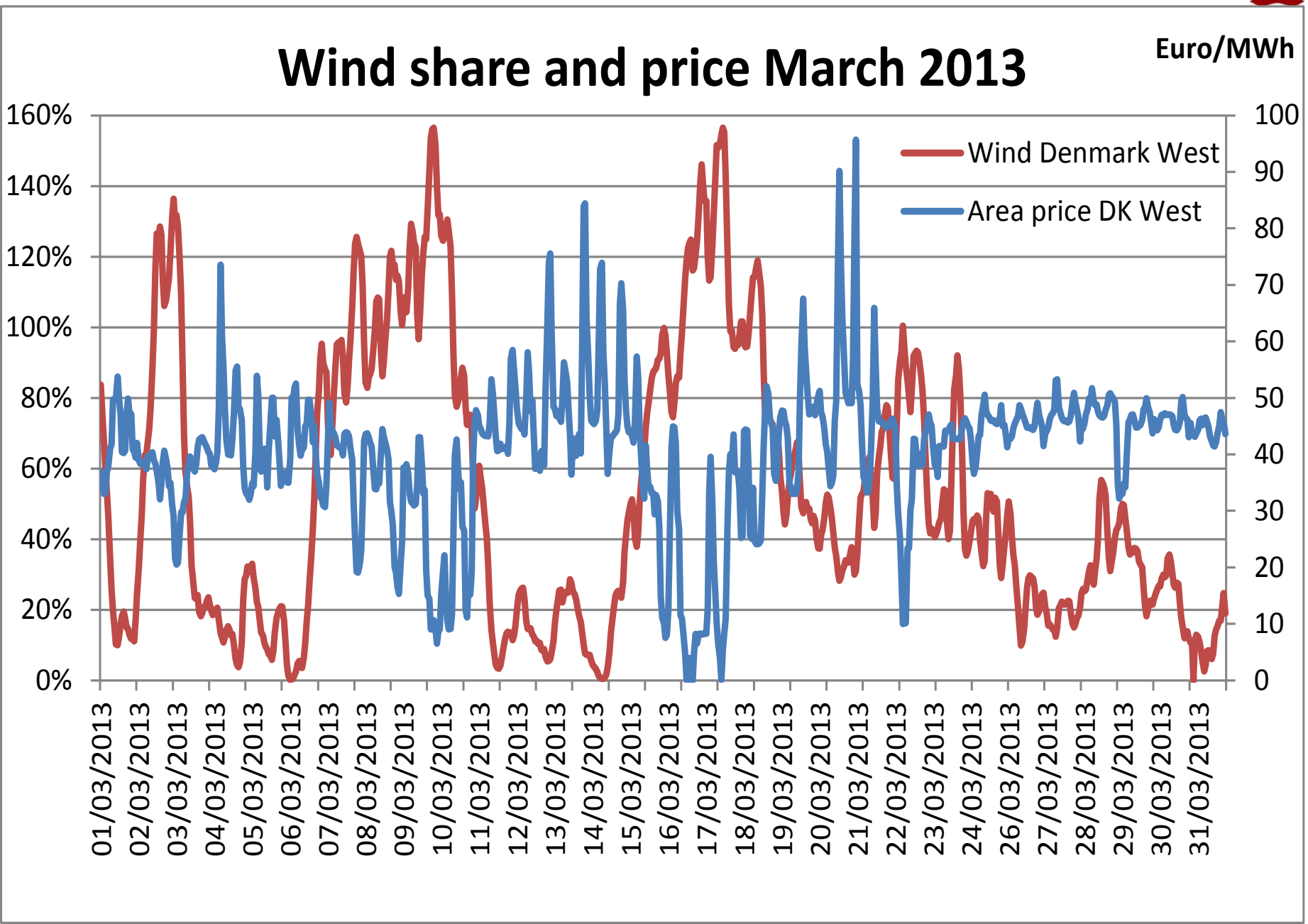


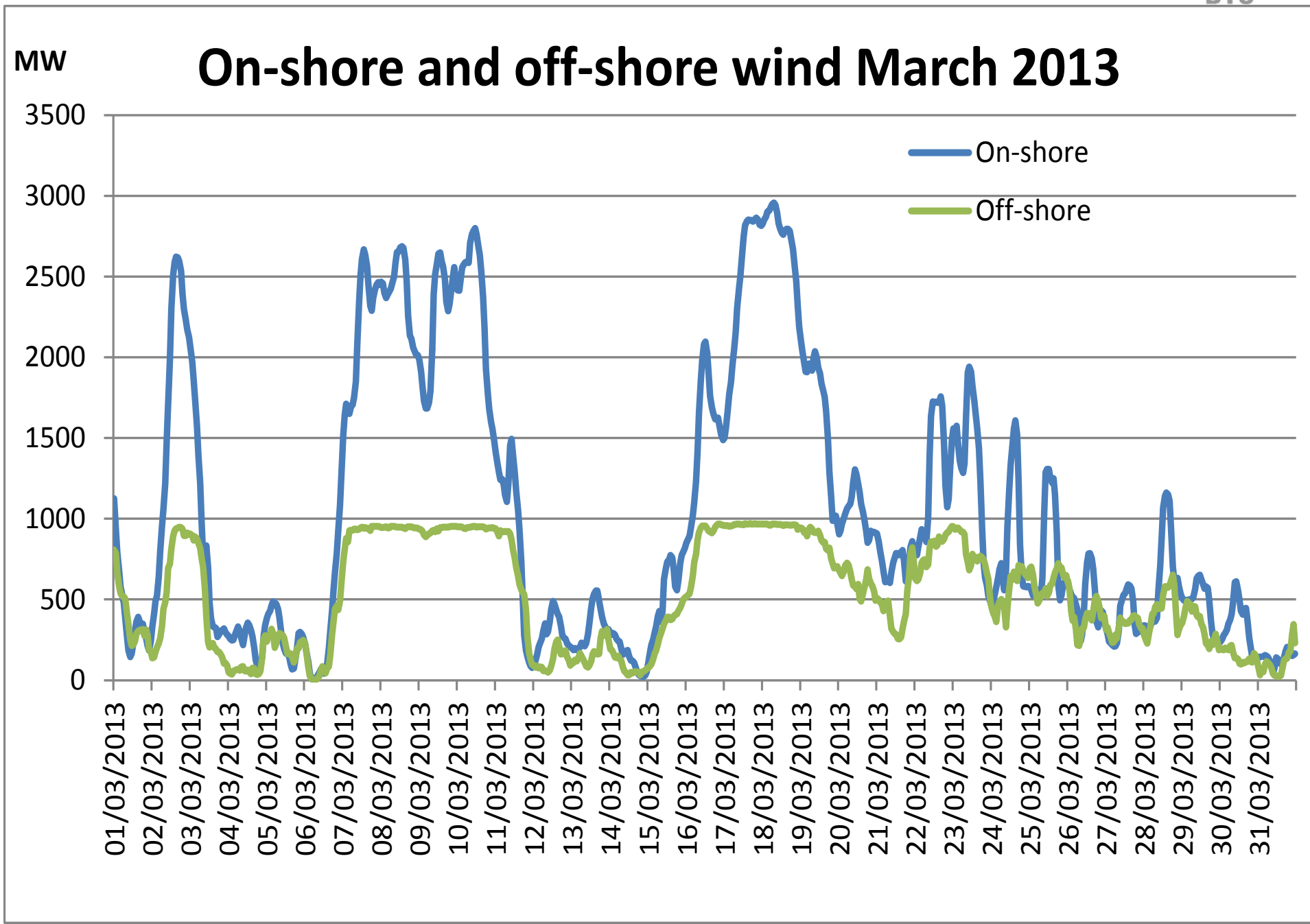
Wind share of consumption March 2013



Wind power covered 40% of power consumption in March for Denmark, (53% in West DK)

Hourly power price is negatively correlated with wind generation




On-shore and off-shore wind March 2013
MW
3500
3000
2500
2000
1500
1000
500
0
On-shore
Off-shore
01/03/2013
02/03/2013
03/03/2013
04/03/2013
05/03/2013
06/03/2013
07/03/2013
08/03/2013
09/03/2013
10/03/2013
11/03/2013
12/03/2013
13/03/2013
14/03/2013
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16/03/2013
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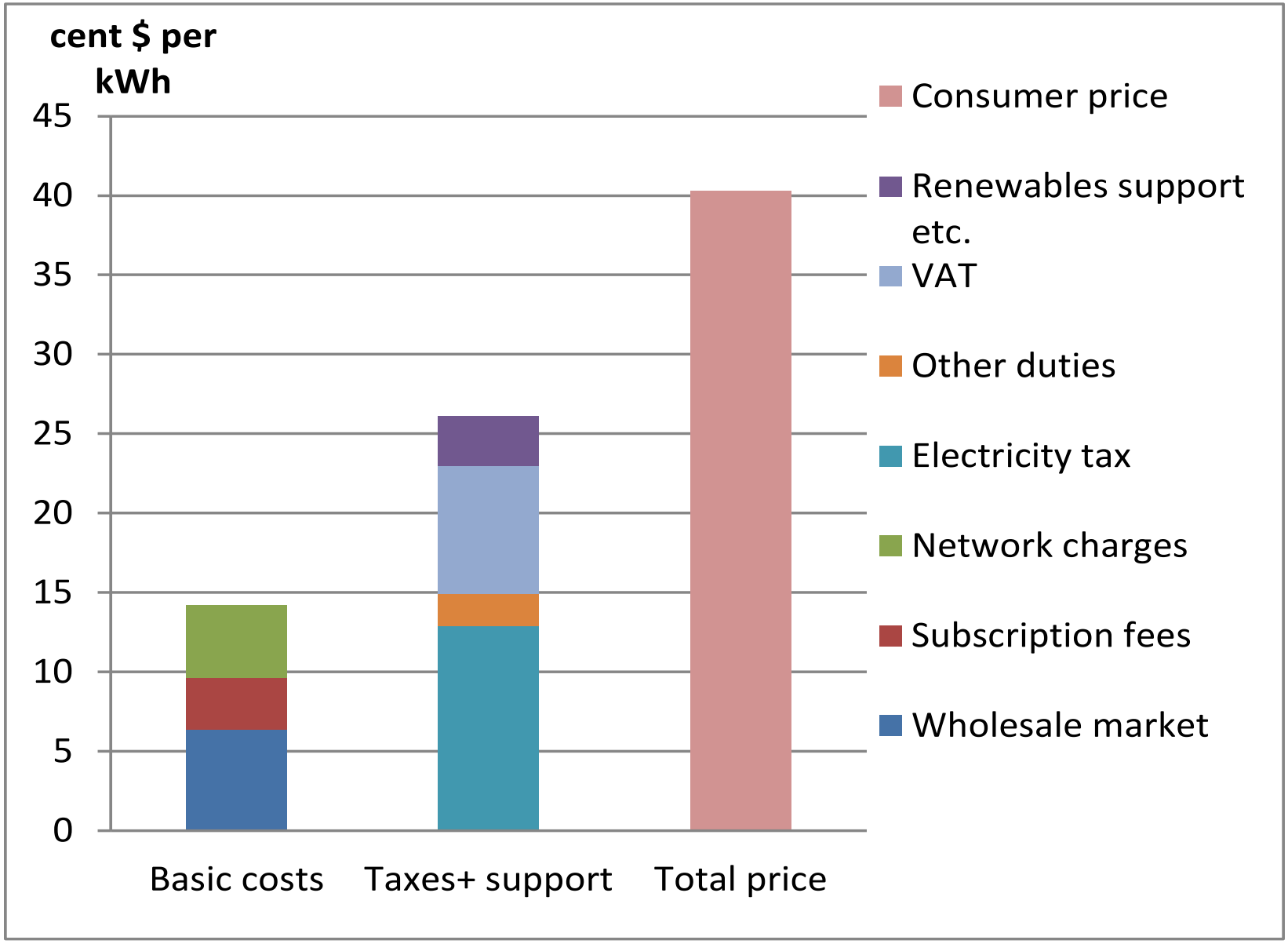
21/03/2013
22/03/2013
23/03/2013
24/03/2013
25/03/2013
26/03/2013
27/03/2013
28/03/2013
29/03/2013
30/03/2013
31/03/2013

The consumer is already paying considerable taxes and willingness to pay have not been a major issue

Electricity price for residential consumer in 2013



Ross Baldick,
Department of Electrical and Computer Engineering,
University of Texas at Austin.

Presented at the 10th International Conference on the European Energy Market,
May 27—31, 2013, Stockholm, Sweden.

West zone ERCOT

- Total installed power generation capacity around 12 GW, (compares to 14 GW in Denmark),
- Total installed wind power generation capacity around 9 GW, **75%**, (compares to 4GW and 30% in Denmark),
- Annual wind energy production as a fraction of electric energy consumption is more than **85%**, (compares to 27.1% in Denmark),
- Monthly wind energy production above **100%** in some months.

DANISH ENERGY STRATEGY 2050

- Political agreement adopted in February 2011 (conservative government coalition)
- At time of adoption, the first of its kind in the world:

  Declared target: **Denmark to become independent of fossil fuels in 2050**
- Reduction of Carbon emission by 30% until 2020
- Exports of clean-tech solutions
- New energy policy initiatives
  - Reduce energy consumption in 2020 by 6%
  - renewable energy in 2020 at 33%

  new 2012 agreement: by 7.6%

  new 2012: wind alone 50%
- In 2035: 100% of electricity from renewable sources

Thank you for your attention!

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